Case Study:
Masen NOOR Ouarzazate Solar Complex
NOOR OUARZAZATE CSP POWER PLANTS
NOOR OUARZAZATE COMPLEX, A GRADUAL DEPLOYMENT OF 580 MW
**NOOR_0 | SOLAR PLANT MAIN TECHNICAL CHARACTERISTICS (1/3)**

**Techno.**
Concentrated Solar Power using parabolic troughs and molten salt Thermal Energy Storage

**Capacity**
160 MWe Gross Capacity

**Storage**
3 hours Thermal Energy Storage

**Cooling**
Wet cooling

**Developer**
ACWA POWER QUARZAZATE

**EPC**

**Price Data**

| Price per kWh* | 0.189 $ |

* evaluated peak hour tariff
Reflective Area: 1 308 000 m²

Number of loops: 400/STN0

HTF: Dowtherm A

HCE tubes: Schott PTR 70

1 hot Tank & 1 cold Tank

Thermal Capacity: 1269MWth (equivalent to 3 hours of storage)

Tank Dimension: ø: 46.5 m / H: 14 m

ST Gross Capacity: 160 MW

Water consumption: ~1 700 000 m³/yr

Project Area: 458ha
NOOR II SOLAR PLANT MAIN TECHNICAL CHARACTERISTICS (1/3)

<table>
<thead>
<tr>
<th>Techno.</th>
<th>Concentrated Solar Power using parabolic trough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>200 MW Gross Capacity</td>
</tr>
<tr>
<td>Storage</td>
<td>&gt; 7 hours</td>
</tr>
<tr>
<td>Cooling</td>
<td>Dry</td>
</tr>
<tr>
<td>Tariff*</td>
<td>0.14 $ / kWh</td>
</tr>
</tbody>
</table>

**Developer**
- ACWA POWER
- SENER
- Sepco III
- POWERCHINA

**Financial Institutions**
- Banque européenne d’investissement
- Clean Technology Fund
- KFW
- THE WORLD BANK

* evaluated peak hour tariff
Reflective Area: 1,779,900 m²

Number of loops: 425/STN2

Solar field Inlet/outlet: 295 °C/393 °C

1 Loop = 4 SCAs
1 SCA = 12 SCEs

2 hot Tank & 2 cold Tank

Thermal Capacity: 3125 MWth (equivalent to 7.3 hours of storage)

Tank Dimension: Ø: 44.1 m / H: 16.6 m

ST Gross Capacity: 200 MW

Water consumption: 280,000 m³/yr

Project Area: ~600 ha
NOOR III SOLAR PLANT MAIN TECHNICAL CHARACTERISTICS (1/3)

- **Techno.**
  - Concentrated Solar Power using tower

- **Capacity**
  - 150 MW Gross capacity

- **Storage**
  - > 7 hours

- **Cooling**
  - Dry

- **Tariff***
  - 0.15 $ / kWh

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**Developer**

- ACWA POWER

**EPC**

- SENER
- Sepco III
- POWERCHINA

**Financial Institutions**

- Agence Française de Développement (AFD)
- Banque Européenne d’Investissement (BEI)
- KfW
- The World Bank

* evaluated peak hour tariff
Reflective Area: 1 321 197 m²

Number of heliostat: 7400 (178m²/Heliostat, 54 facet)

HTF: Molten Salt (NaNO3 (60%)/ KNO3 (40%))

Receiver: 660 MWth

1 hot Tank & 1 cold Tank

Thermal Capacity: 2770MWth

Tank Dimension: Ø: 41.3 m / H: 14 m

Cold: 290 C (to receiver)
Hot: 565 C (receiver outlet)

Tower Height: 247m

ST Gross Capacity: 150MW

Water consumption: 155 000 m³/yr

Project Area: ~ 600ha
### NOOR QUARZAZATE POWER PLANTS

<table>
<thead>
<tr>
<th></th>
<th>NOORo I</th>
<th>NOORo II</th>
<th>NOORo III</th>
<th>NOORo IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology</strong></td>
<td>CSP Parabolic trough</td>
<td>CSP Parabolic trough</td>
<td>CSP Tower</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td><strong>Capacity</strong></td>
<td>160 MW</td>
<td>200 MW</td>
<td>150 MW</td>
<td>70 MW</td>
</tr>
<tr>
<td><strong>Cooling</strong></td>
<td>Wet</td>
<td>Dry</td>
<td>Dry</td>
<td>-</td>
</tr>
<tr>
<td><strong>Thermal Storage</strong></td>
<td>3h</td>
<td>7h to 8h</td>
<td>7h to 8h</td>
<td>-</td>
</tr>
<tr>
<td><strong>Annual Production</strong></td>
<td>520 GWh</td>
<td>699 GWh</td>
<td>515 GWh</td>
<td>125 GWh</td>
</tr>
<tr>
<td><strong>Surface</strong></td>
<td>485 ha</td>
<td>600 ha</td>
<td>580 ha</td>
<td>137 ha</td>
</tr>
</tbody>
</table>

- **NOORo I** in operation since beginning of 2016
- **NOORo II and NOORo III** under construction
- **Start of construction of NOORo IV** in 2017
CONSTRUCTION & START-UP
- Establishment of a responsibility assignment matrix at the beginning of each project
POWER PLANTS – SCOPE OF INTERVENTION

Services Awarding

Independent Engineer Services
- Request for Proposals preparation
- Evaluation of Technical and Financial Proposals
- Certification of Initial and Final Tests
- Request for Proposals preparation
- Evaluation of Technical and Financial Proposals
- Support for Design Review
- Specific missions for construction activities inspections
- HSE
- Quality Assurance
- Specific activities

Technical Advisor Services

Specific Audits and inspections

Payment Milestones approval
- Ensure the milestones are reached in order to request for funds
- Ensure the appropriate documents are provided
- Manage the mission of Lender Technical Advisor

Funds disbursement
POWER PLANTS – SCOPE OF INTERVENTION

Engineering

Design Review

- Ensure compliance with the contractual documents
- Interfaces with Masen common infrastructures
- Review of design plans and drawings including the specification of equipment
- Review of O&M Manuals
- Selection of drawings for ONEE’s approval
- Telecommunication system with the dispatching center
- Approval of the Plant’s electrical protection settings
- List of prerequisites before first energization
- List of prerequisites before first synchronization

Interfaces with ONEE (Grid operator)

Logistics and Procurement

Approval of agreed manufacturers

- Factory inspections

Factory Acceptance Tests

- Support for the delivery of permits and authorizations
POWER PLANTS – SCOPE OF INTERVENTION

**Construction & Commissioning**

- **Construction Management**
  - Ensure compliance with the contractual documents
  - Follow-up of construction progress
  - Analysis of Project scheduling
  - Integration of the Plant with Masen Infrastructures
  - Follow-up of Industrial Integration
  - Follow-up of employment statistics
  - Commissioning procedures analysis
  - Follow-up of commissioning progress
  - Analysis of Project scheduling
  - Certification by the Independent Engineer

- **Quality Assurance**
- **HSE Management**
- **Commissioning Management**

**Acceptance Tests**

- **Initial Performance Tests**
- **Final Performance Tests**
  - Performance Tests procedures analysis
  - Witness and Approval of Performance Tests results
  - Certification by the Independent Engineer
LESSONS LEARNED
Mirrors cleanliness impact directly the performance of the plant

2 additional cleaning trucks have been procured in beginning of 2017

Mirrors cleanliness factor is expected to be higher after the completion of NOORo II & NOORo III construction
Overall the production during this semester was good. However it was impacted by following:

- the cleanliness factor affected by ongoing works in the complex and weather conditions
- Learning curve of the Operator (NOMAC) especially during cloudy days

*Expected generation is calculated using the Performance Model with reference data and the weather data measured on site*
**NOORo I – RATIO PEAK GENERATION S2 2016**

<table>
<thead>
<tr>
<th>2nd semester 2016 (MWh)</th>
<th>Peak generation</th>
<th>Off-Peak generation</th>
<th>Ratio Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 170</td>
<td>138 105</td>
<td>23,5%</td>
<td></td>
</tr>
</tbody>
</table>

**Peak Hours generation (MWh)**
- July: 33,685 MWh
- August: 27,912 MWh
- September: 24,516 MWh
- October: 19,484 MWh
- November: 16,316 MWh
- December: 16,191 MWh

**Off-Peak Hours generation (MWh)**
- July: 8,231 MWh
- August: 4,760 MWh
- September: 6,524 MWh
- October: 4,807 MWh
- November: 8,342 MWh
- December: 9,506 MWh

**Ratio Peak generation**
- July: 20%
- August: 15%
- September: 21%
- October: 20%
- November: 34%
- December: 37%

*Very good production during peak hours thanks to the progress made by the O&M team*
NOORo I – PLANTS CONSUMPTION (JANUARY – APRIL 2017)

**Electricity**

<table>
<thead>
<tr>
<th></th>
<th>Jan. 17</th>
<th>Févr. 17</th>
<th>Mars 17</th>
<th>Avr. 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consommation électrique importée du réseau (MWh)</td>
<td>1,359</td>
<td>1,149</td>
<td>1,096</td>
<td>1,149</td>
</tr>
</tbody>
</table>

**Cumul 2017 de la consommation électrique (MWh)**

- Cumul de consommation électrique: 14,743 MWh

**Diesel**

<table>
<thead>
<tr>
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<th>Mars 17</th>
<th>Avr. 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consommation diesel (m3)</td>
<td>68</td>
<td>139</td>
<td>49</td>
<td>51</td>
</tr>
</tbody>
</table>

**Cumul 2017**

- Cumul de consommation diesel: 3,07 m3

**Eau**

<table>
<thead>
<tr>
<th></th>
<th>Jan. 17</th>
<th>Févr. 17</th>
<th>Mars 17</th>
<th>Avr. 17</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consommation d'eau (m3)</td>
<td>109,445</td>
<td>76,383</td>
<td>3,07</td>
<td>3,57</td>
</tr>
</tbody>
</table>

**Cumul 2017**

- Cumul de consommation d'eau: 479,545 m3

- Consommation par unité de production: 3,46 m3/MWh
**Wet Cooling System**

**NOORo I: 160 MW**
Annual water consumption:
1 750 000 m3

**Dry Cooling System**

**NOORo II: 200 MW**
Annual water consumption:
288 000 m3

**NOORo III: 150 MW**
Annual water consumption:
155 000 m3
Main heavy equipment requiring transport authorization:

- HTF / SALT Heat exchangers: 6 x 362 T
- Generator: 237 T
- HP turbine: 134 T
- Pre-heaters 2x92 T
- Evaporators 2x146 T
- Reheaters 2x92 T
- Main Transformer 130 T
- Condenser 140 T
- HTF heaters: 2 x 90 T

Assessment to be conducted at the beginning of the project:
- Selection of the routing during the bidding process
- Coordination with the involved authorities in order to define any necessary reinforcement works
NOORo I - INDUSTRIAL INTEGRATION

% industrial integration

EPC Committed expenses

Committed % industrial integration over the period: 34.7%

EPC Committed expenses with local companies: 1,940 Mdh

Total EPC budgeted costs for the project: 5,581 Mdh

Expenses split by main EPC works (committed by local companies):
- Solar field collectors (mirrors supports): 27%
- Salts and water tanks and reservoirs: 22%
- Piping and cables: 8%
- Piling and civil works: 10%
- Mechanical and electrical erection: 33%

EPC expenses

% total industrial integration: 34.7%

EPC expenses with local companies: 1,940 Mdh

Total EPC budgeted costs for the project: 5,581 Mdh

Expenses split by main EPC works (paid to local companies):
- Solar field collectors (mirrors supports): 26%
- Salts and water tanks and reservoirs: 23%
- Piping and cables: 7%
- Piling and civil works: 10%
- Mechanical and electrical erection: 34%